PROJECT WHIRLWIND

SUMMARY REPORT NO. 28
FOURTH QUARTER 1951

Submitted to the

OFFICE OF NAVAL RESEARCH
Under Contract N5ori60
Project NR 048-097

and the

UNITED STATES AIR FORCE
Under Contract AF19(122)-458

DIGITAL COMPUTER LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge 39, Massachusetts

5. INPUT-OUTPUT

5.1 MAGNETIC TAPE

The temporary magnetic-tape setup mentioned in Summary Report 27 has been found to operate quite satisfactorily. The temporary system is still connected with the computer. It is being tested with various modes of operation, and it is sometimes used with the computer on application problems. In this way the system can be employed for useful computation, and at the same time provide performance data and serve to acquaint operators with the programming problems.

Using the results obtained in the testing of the temporary setup, the design of the equipment for the final system is being carried out. The final magnetic-tape system will work with the in-out control described in Summary Report 26. The decision to group the magnetic-tape heads in pairs to reduce difficulties with tape blemish will be applied to the final system, and this has necessitated a few superficial changes in the design of in-out control.

The computer, by setting up the in-out switch, will be able to select one of four tape units and to drive it either forward or reverse and to select the mode of operation. The three possible modes of operation are read, record, and re-record. The re-record mode is one in which a portion of the information in a previously recorded tape is replaced. This mode involves both reading and recording -- reading to locate the desired position, and recording to insert the new information.

The information is put on the tape in blocks of a length determined by the computer, with the spaces between blocks long enough to allow the tape to stop -- about 0.2 inch. The blocks are made up of lines of information across the tape. These lines are spaced at a maximum density of 100 per inch. Because of the grouping of the 6 heads into 3 pairs, there are effectively only 3 channels across the tape. Two of these channels are used to record data received from the computer, and the third is used as an index channel in which a pulse is recorded whenever there is information in the other two channels. Thus 8 lines along the tape are needed to record one 16-binary-digit computer word. The words are split up during recording and assembled during reading by in-out control, so that the programmer does not have to arrange for these operations. The programmer does have to make sure that reading is done with the tape moving in the same direction as when it was recorded, so that the words will be assembled correctly.

During a recording operation, a special character -- called a block mark -- is automatically recorded as the first line in each block. This block mark is used in reading to determine the beginning of a block of information, and the control is arranged to detect a block mark and activate the reading circuits. This feature along with others allows the computer to keep track of the location of information on the tape by reading only one line in a block and counting it, without having to spend time reading all of the information in each block. The block mark is also used during the re-record operation to trigger the circuits from the reading to the recording mode at the proper time. The fact that a block mark must be detected in order to activate the reading circuits makes it possible to start the tape in the middle of a block of information without getting into trouble.

5.2 MAGNETIC DRUMS

Two magnetic-drum systems are being constructed by Engineering Research Associates of St. Paul for use with the Whirlwind computer. These have been designated as the auxiliary-storage drum system and the buffer-storage drum system. A brief description of this equipment was given in Summary Report 26.

The auxiliary-storage drum is to be used as a large-capacity storage to supplement the high-speed electrostatic storage in the computer. This drum is designed to have 2048 registers around its circumference and to have 12 groups of 16 heads. This arrangement provides a total capacity of 24,576 16-digit registers. It will be used for storage both of numerical data and of computer subprograms. The system will be connected so that transfers of information can take place only between the drum and electrostatic storage. These transfers will take place by way of the in-out register and will involve use of the in-out switch and the in-out control. This method of integration was chosen because it permits the most straightforward design. However, the addition of more elaborate control features at a later date is not precluded.

Several modes of operation for this equipment are being planned. These are described in some detail in Memorandum M-1358. Basically, they provide a programmer with a choice of either single-word or block transfers and of various methods for specifying the drum registers to be referred to. For single-word transfers an average wait-time of 8 milliseconds will be necessary in order to locate the desired drum address. For

From Lincoln Lab
GPR
Div 6 1 June 1952

6.3 INPUT-OUTPUT SYSTEM

At the present time there are several means of extracting information from, and injecting information into, the Whirlwind I Computer. These include a photoelectric and a mechanical punched-paper-tape reader, a typewriter, a paper-tape punch, several cathode-ray-tube display scopes, and a camera for automatically photographing a CRT display. Each of the equipments in the present system requires a separate computer order to operate it, and we expect to add in the near future more of each of the above units and a magnetic-tape system.

To increase the size of the present system would require more computer orders than are available; therefore, a consolidated in-out system is being built to handle all input-output units (excepting the magnetic drum for storing radar data). In this system only one computer order is needed to select a unit. The address of this order will set up a multiposition matrix switch that will select the desired unit and its mode of operation. Two more computer orders are needed to complete the operation, one to read and one to record. The addresses of these orders are used to specify the storage registers to put the data in or take it from. The use of a read and a record order is somewhat redundant, since the mode is specified by the first order, but it makes for a simplification of equipment.

The status of the various sections of the in-out system that are being worked on at present is described below.

6.3.1 Magnetic Tape

6.3.1.1 Interim Magnetic-Tape System

The interim magnetic-tape system is now in operation in the Whirlwind computer as a temporary installation for experimental purposes. It has been assembled in the hope that some of the problems inherent in the use of magnetic-tape storage will be revealed through the use of programs which operate this system in conjunction with the computer. The experience thus gained should be of considerable value in the design and building of the final system.

In so far as possible, the interim system uses standard Whirlwind I test equipment as building blocks. Thus its mode of operation is frequently the most expeditious rather than the most efficient. The final results obtained from the interim system are approximately the same as those of the final system; but the coding procedures necessary to achieve those results are different in the 2 systems.

The tape-handling device used is a Raytheon magnetic-tape unit that has been specially designed for the storage of digital data. It will handle about 1000 feet of 1/2-inch tape on which information is stored in six channels across the width of the tape. Maximum recording density is about 100 lines per inch, and the tape runs at 30 inches per second.

The interim magnetic-tape system serves as an intermediary between the Raytheon unit and the computer. The interim system makes it possible for the computer to record binary information on the magnetic tape and read it back when desired. Word storage on the magnetic tape is in series-parallel form; therefore, transfers to and from the tape are made by a series of read-shift or record-shift operations.

One of the problems encountered in the use of the Raytheon magnetic-tape unit is the presence of blemishes and dust on the tape itself. Briefly, the effect of both blemishes and dust

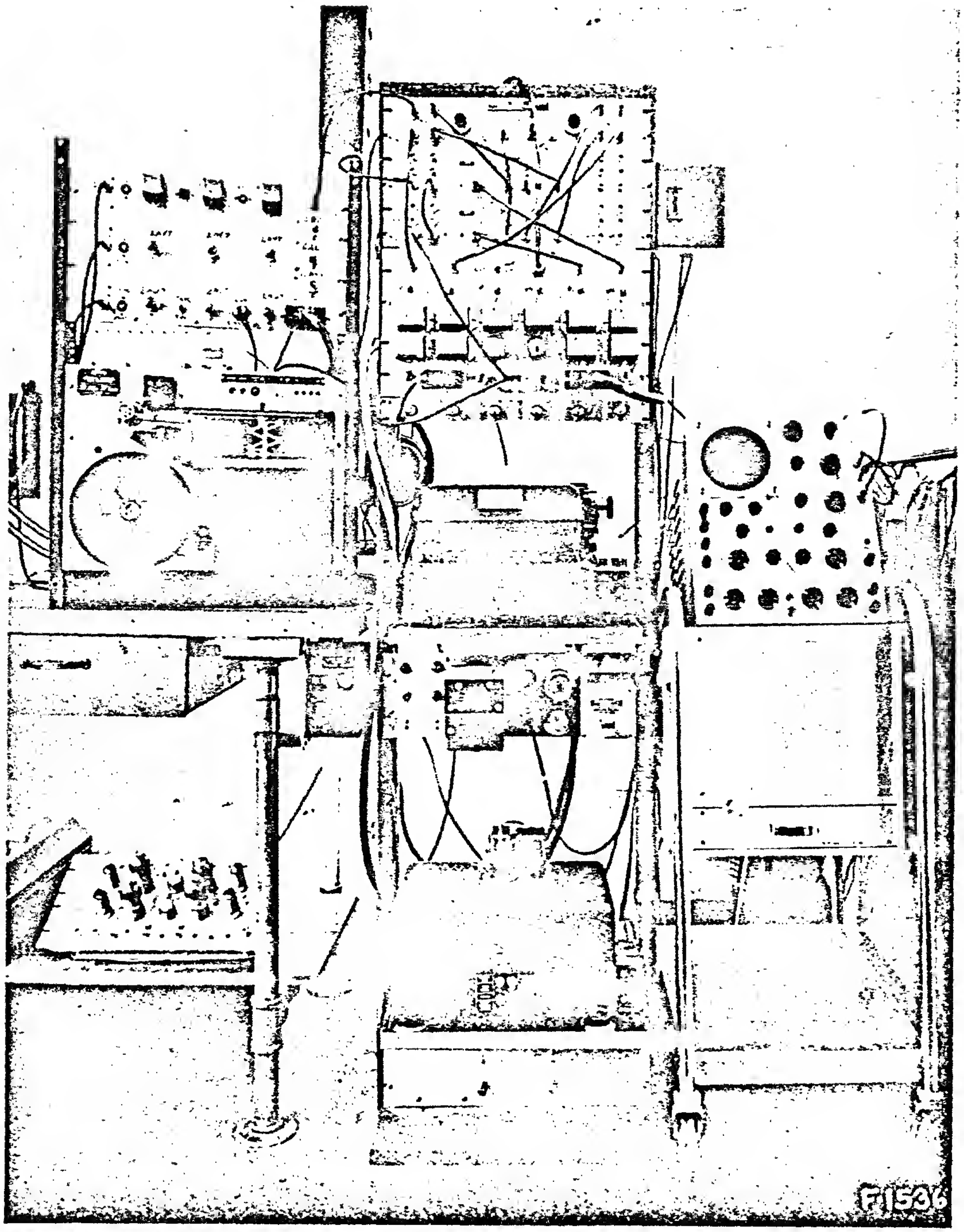

Fig. 6-6. Magnetic-tape print-out system.

is to hold the tape away from the head and cause a pulse to fail to be read back or to fail to be recorded, with the consequent absence of that pulse on the read-back. Preliminary experiments seem to indicate that although dust and blemishes could cause dropping out of a pulse where one should have been recorded, they seldom, if ever, cause pulses to occur where none were intended. (It is conceivable that dust, by raising the tape from the head or causing the tape to bounce, could cause the faulty erasure of a pulse previously recorded.) These experiments also established the fact that a blemish might cause 2 successive dropouts on the same channel, or dropouts on 2 adjacent channels. A case was never observed where the dropouts extended across 3 or more adjacent channels. This fact suggested a method of minimizing the effect of tape blemishes and dust and thus improving the reliability of the system. The 6 channels of the tape unit were connected into 3 pairs, with one channel of a pair being separated from the other channel by 2 interposing channels. The 2 channels of each pair are operated in parallel, and in this manner if a pulse is lost on one channel because of a blemish, it will be picked up on the other. This reduces the effective number of channels to 3, but it permits the use of the whole tape, and does not require any extra equipment.

Initial testing was accomplished through the use of 2 test programs that recorded information on the magnetic tape and then read it back into the computer and checked the information read back against that recorded. One test program displayed the errors on an oscilloscope; the other printed them out on the Flexowriter typewriter. Results obtained in tests made over a period of more than 3 months indicate that it is possible to record over the entire tape and consistently read back the information without error. Test runs made without the redundant reading system indicate that the dropouts experienced in a non-redundant reading are usually consistent; that is, if the tape is recorded once and read back and forth several times, the same errors usually appear. Similar tests show that dropouts on one channel are not duplicated on its parallel channel.

Operation of the interim system to date gives evidence of a reliable medium of storage in magnetic tape. Present work is directed toward the simplification of operation of the system to permit its use by computer operators without engineering attention, and toward the investigation of possible improvements in the tape-handling qualities of the Raytheon tape unit.

6.3.1.2 Printing from Magnetic Tape

The developmental model of the equipment required for the printing-out of information from magnetic tape has been constructed and is now undergoing tests. This output equipment operates independently of the computer from recordings made by the computer in 6-digit printer code at up to 150 characters per second. A photograph of the equipment is shown in Fig.6-6.

Sixty-thousand typewriter characters (decimal digits, symbols, etc.) can be recorded by the computer on a 100-foot reel of magnetic tape in less than 7 minutes; 2 hours are required for the printing-out equipment to transcribe this quantity of information at 10 characters per second.

The 6-digit binary code specifying a single typewriter character is recorded serially in the two information channels available on the magnetic-tape equipment using the redundant

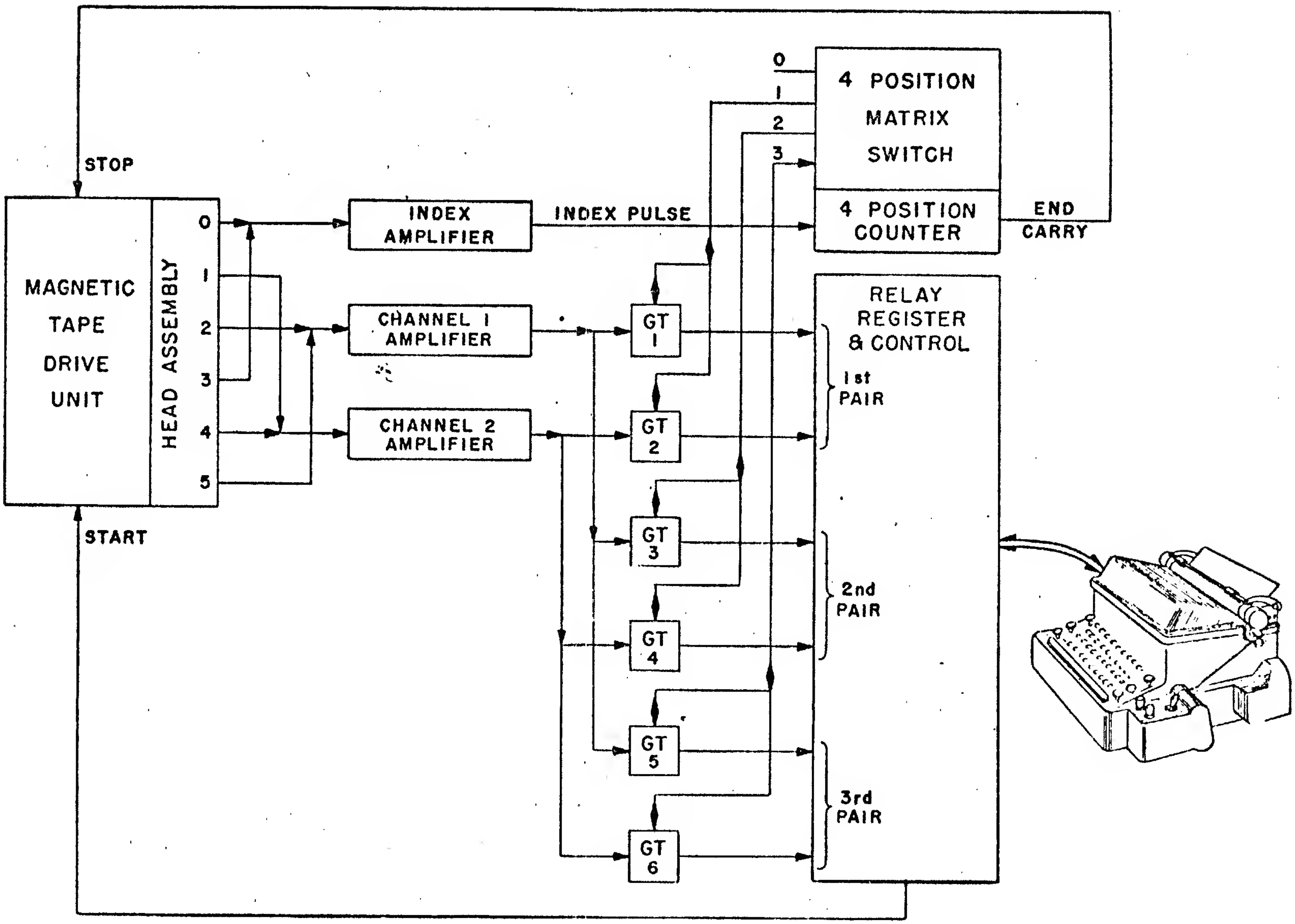

Fig. 6-7. Magnetic-tape print-out system.

CONFIDENTIAL

recording scheme. One typewriter character occupies 4 lines on the tape; the first line is a dummy on which only an index mark, used to start the equipment, is recorded, and the next 3 lines each contain 2 of the 6 digits. The essential features of the print-out system are shown in the accompanying block diagram, Fig.6-7. Gates one through six are 2D21 thyratrons which are fired by coincidence of the information pulses with the setting of the diode matrix switch. The latter is controlled by the index pulse count, thus distributing the data to reconstruct the original code for use by the printing mechanism. The count of 4 index pulses stops the tape mechanism. Completion of the printer cycle clears the thyratrons, resets the counter, and starts the tape to read in the next character. The spacing required (0.2 inch) between characters to permit stopping the tape before the next symbol is intercepted limits the maximum recording speed. The function of the control panel is to synchronize the interlock,the tape and printing mechanisms to permit continuous automatic operation.

Problems encountered in this development have been those of reliably operating flip-flops in conjunction with relay- and cam-operated current-breaking contacts, and of tailoring circuits and timing sequences to fit the Flexowriter equipment circuits and to use the available cable connectors without modification.

Approximately one million consecutive characters, equivalent to about 40 hours of operation, have been printed from magnetic tape without error. The equipment is now available for limited use by application groups. Recording of computer output on magnetic tape will reduce computer print-out function time by a factor of 20; the time consumed by the computer's direct print-out equipment is about 150 milliseconds per character compared to 7 milliseconds per character for recording on magnetic tape. Further increase in recording speed could be achieved by providing additional storage registers in the output equipment to permit recording characters in more compact groups on the tape. A 100 per cent increase in output equipment would permit an increase of only 50 per cent in recording speed, however.

6.3.1.3 Final Magnetic-Tape System

The final magnetic-tape system for the computer will contain 5 magnetic-tape drive units. Four tape units will be available to the computer, and one will be connected to a separate printing system. A simple manually operated or computer-operated switch will allow the unit connected to the print-out system to be interchanged with a unit connected with the computer, thus eliminating manually exchanging tapes.

With this system the computer will be able to select any one of the 4 tape units, and cause it to run backward or forward while either reading or recording. The information will be recorded on the tape in blocks, and each block will contain an identifying character to permit the computer to locate information on the tape. An additional feature of the system is a rerecording mode which will permit the computer to replace a block of information on a previously recorded tape without disturbing other information.

In order to provide the fast switching for the rerecord operation and to minimize the time spent by the computer waiting for action, the switching between units and between modes is done electronically. This switching is somewhat complicated by the fact that the tape heads have only one two-terminal winding, and this same winding is used for recording, reading, and erasing.

The final design of the switching circuits will accomplish the switching in less than a microsecond; however, in the case of switching from recording to reading, the switching transient blocks the reading amplifier for about 3 milliseconds. The transient does no harm, since this type of switching is done only between blocks on the tape and it takes at least 5 milliseconds for the tape to move to the next block.

The design of the equipment for the final tape system has been completed, and models of all of the circuits have been tested. The final panels are now being constructed. The design includes, besides the switching and amplifying panels, circuits for pulse shaping and gating to allow the system to be connected to, and operated by, the computer in-out control.

6.3.2 Display System

The results of calculations by the Whirlwind Computer may be made sensible to humans by the display of spots on a cathode-ray tube. In Fig. 6-8 is shown the point-by-point plot of a 7th order polynomial with the values of the roots printed out. The versatility of the Whirlwind display is shown in Fig. 6-9. The entire pattern of vectors, numbers, and letters was displayed automatically in approximately one second.

In the Whirlwind display system there are available 5 slightly modified Dumont 304-H 5-inch oscilloscopes and two special 16-inch magnetically deflected scopes using K1048P7M CRT's. The 304-H's are changed by the addition of a flip-flop coupled to the grid of the CRT so that the electron beam may be turned on and off by 0.1-microsecond pulses. The standard direct coupled amplifiers of the 304-H's are used to position the electron beam. An "on" period of about 100 microseconds is needed to produce a spot that will remain visible on the P7 phosphor for one minute in a dimly lighted room. One 304-H has a CRT with a P11 phosphor and is used with a Fairchild oscilloscope camera to record displays.

The 16-inch display scopes have specially designed direct-coupled current amplifiers to drive the magnetic deflection gate. These amplifiers take about 30 microseconds to deflect the beam from one edge of the tube to the other with a step input. However, display on the 16-inch tubes can be faster than on the 5-inch tubes, since about 5 microseconds is sufficient intensification to cause a spot to persist for one minute on the magnetically focused CRT. The electron beams in the 16-inch scopes are also controlled by flip-flops. The ratio of spot size to tube face diameter is much smaller for the 16-inch tube than for the 5-inch tube. The resolution available on the 16-inch tube is therefore much greater than the 5-inch tube can provide.

One of the 16-inch scopes is mounted in a wheeled cabinet (Fig. 6-10) for close viewing; the other is mounted on a high shelf so as to be visible to many people. The Fairchild camera may be used with the 16-inch tube to give clearer detail than obtainable with the 5-inch tube. Plans call for another cabinet-mounted 16-inch scope and a rack-mounted one with a P11 phosphor for the exclusive use of the camera.

Four computer orders are used for display purposes. One sets up the horizontal deflection of the display scopes; the other 3 set up the vertical scope deflection and produce "Intensify" pulses for turning on the electron beams of the display scopes. These 3 orders are identical, but their intensify pulses are fed on 3 separate lines to all of the scopes. Any one, two, or all three pulses may be selected at each scope to provide several "filtered" displays